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UK CL (Edition K) F1W WCK WCX WEX
INT CL[5] F04B 21/00 21/02 43/00 43/04
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(54) **Membrane micropump**

(57) A micropump comprises a liquid inlet (1), a pump chamber (11) variable in volume by a membrane (4a) and a liquid outlet (2). The liquid inlet communicates constantly with the pump chamber (11) whereas a valve (8') is provided between the pump chamber (11) and the liquid outlet (2). The flow resistivity of the liquid inlet is sufficiently high in order to assure that the amount of liquid which flows back through the inlet during the thrust phases of the pump cycle is sufficiently small compared to the amount of liquid flowing in the forward direction through the outlet valve (8') during the same thrust phases. A piezoelectric element (6) activates the membrane (4a).

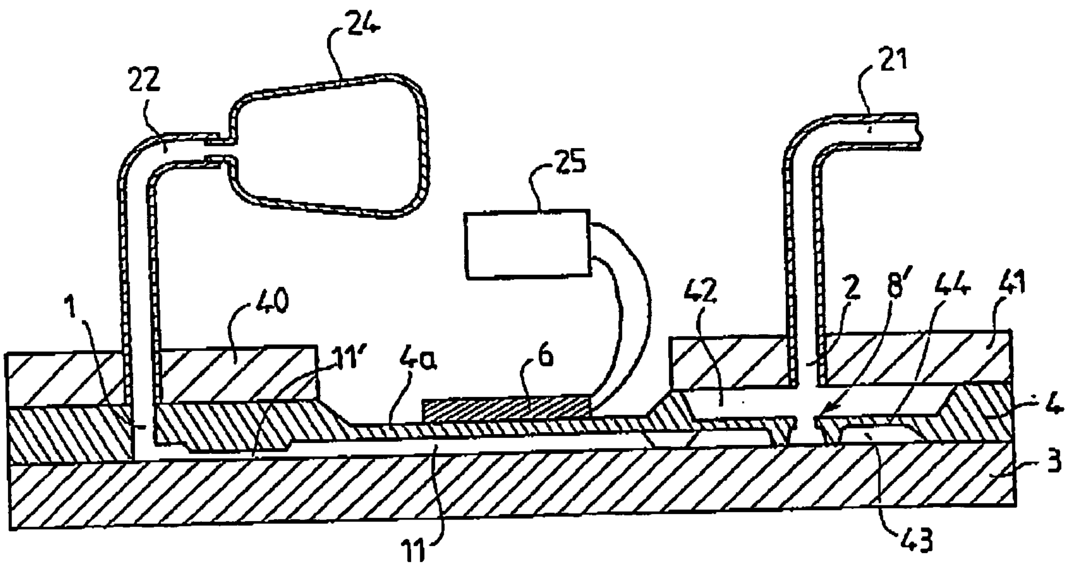

FIG. 2

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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

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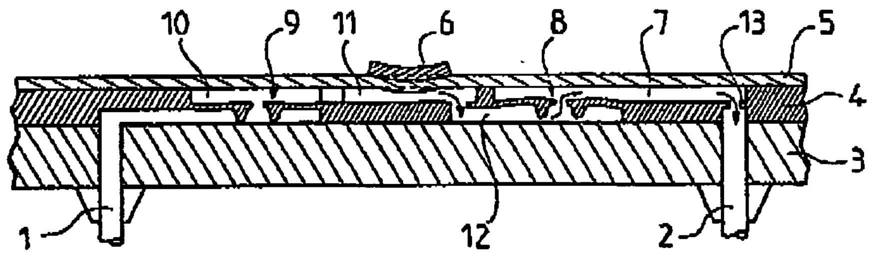

FIG. 1a

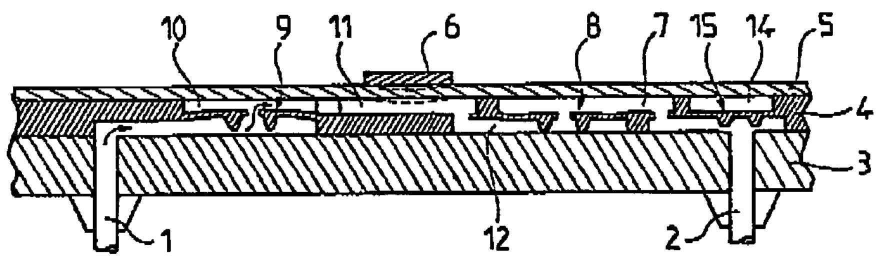

FIG. 1b

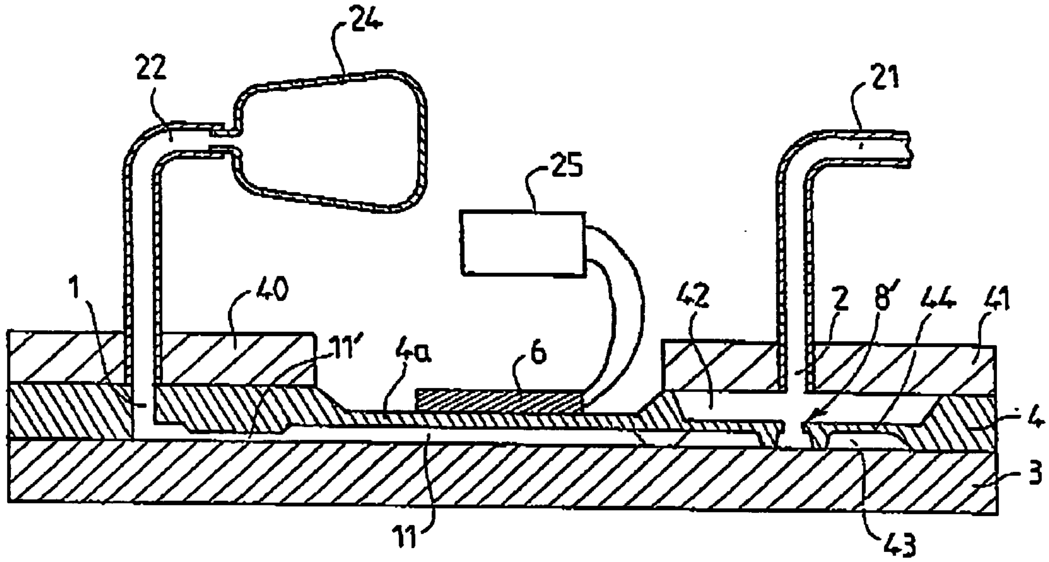

FIG. 2

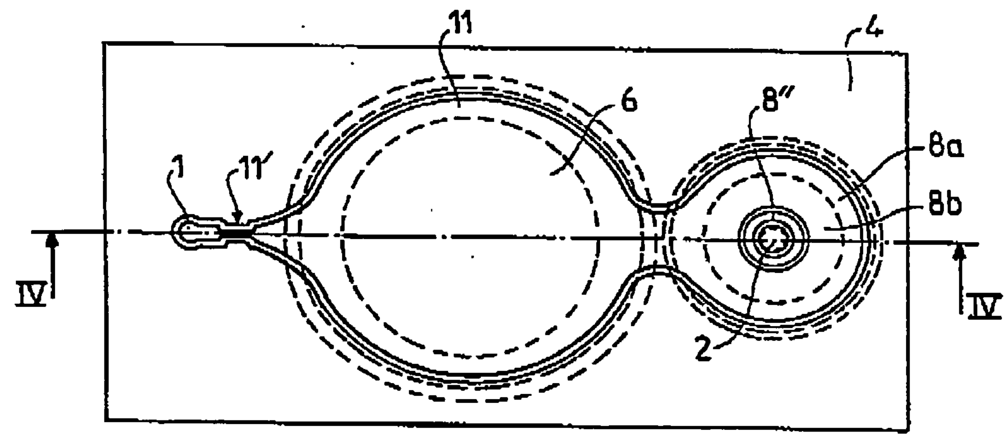

FIG. 3

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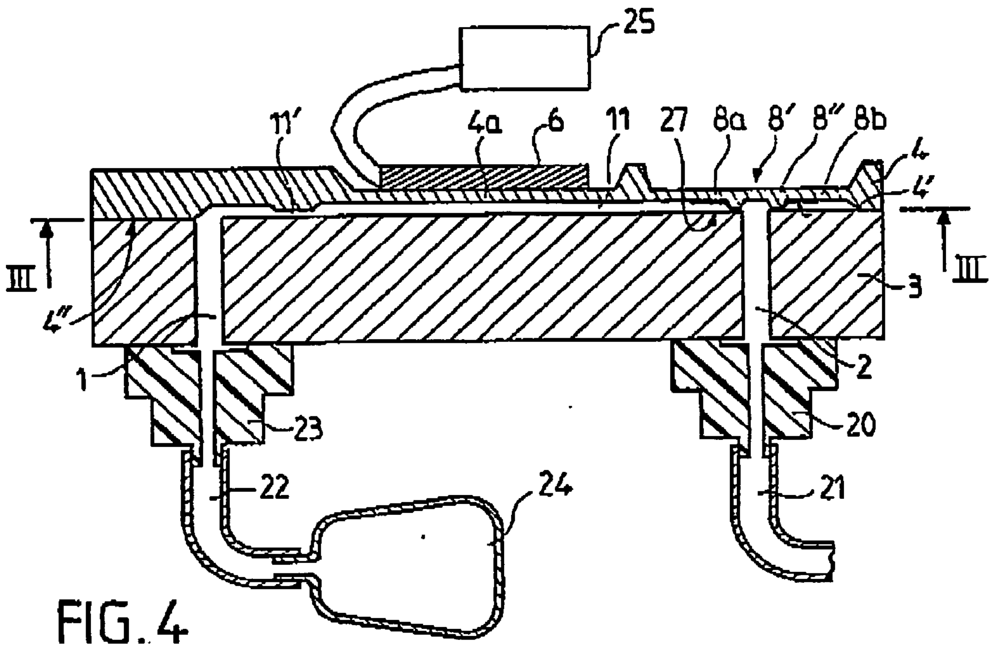
25
11'
4a
6
11
27
8a
8'
8"
8b
4
4'
III
III
4"
3
1
2
23
20
22
24
21

FIG. 4

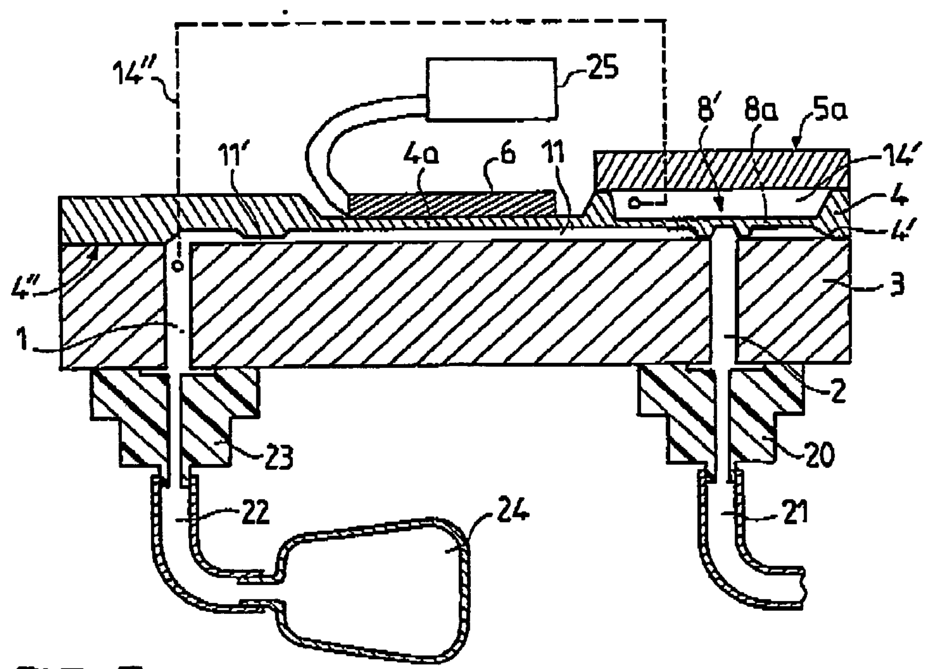
14"
25
8'
8a
5a
14'
11'
4a
6
11
4
4'
4"
3
1
2
23
20
22
24
21

FIG. 5

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MICROPUMP

FIELD OF INVENTION

The present invention relates to a micropump comprising at least one liquid inlet, a liquid outlet, a pump chamber between said liquid inlet and said liquid outlet, said pump chamber being formed between a plate, and a pump membrane which is capable of reciprocatingly increasing and decreasing pressure in said pump chamber, wherein said liquid inlet is separated from said liquid outlet by a valve means, comprising at least one valve between said liquid outlet and said pump chamber and operating such as to permit flow of liquid from said pump chamber to said liquid outlet when the pressure in the pump chamber is increased.

BACKGROUND ART

In the art of designing micropumps e.g. for medical applications where the inlet side of the pump is connected to a liquid drug reservoir and the outlet side to an injection needle or the like, it is known to design such pumps such as to comprise two or even three valve members between the liquid inlet and the liquid outlet of the pump.

In an article of H.T.G. Van Lintel, F.C.M. Van De Pol and S. Bouwstra published in "SENSORS and ACTUATORS" , 15 (1988) 153-167 the authors propose such micropumps with two or three valves. Figs. 1a and 1b of the present application reproduce the

two pump embodiments of said article for the sake of better understanding of the present invention.

Fig. 1a shows a 2-valve micropump comprising a lower glass plate 3, an upper glass plate 5 and a silicon wafer 4 sandwiched between the two glass plates. The silicon wafer comprises a variety of surface structures on both sides which act as connection areas and valve elements as well as pump chambers.

Liquid is drawn in through inlet 1 and passes through valve 9 if the latter is in its open position such as illustrated in Fig. 1b. From a liquid chamber 10 behind valve 9 the liquid passes into pump chamber 11 which communicates constantly with liquid chamber 12. The latter is separated from chamber 7 by valve 8 through which liquid may flow to the liquid outlet 2, passing chamber 7.

The upper glass plate 5 carries a piezoelectric element 6 intimately connected thereto across the entire contact area between the piezoelectric element and the glass plate in order to create a downwards bending of the glass plate 5 when the piezoelectric element is put under electric tension resulting in a horizontal contraction of the piezoelectric element 6.

This downward bending of the glass plate 5 results in a decrease of the volume of the pump chamber 11, such that valve 9 is pressed into its closed position (illustrated in Fig. 1a) whereas valve 8 is opened, permitting the liquid to flow into outlet 2. During release of the pressure in pump chamber 11 following deactivation of the piezoelectric element 6, the volume of the pump chamber 11 increases and the pressure therein decreases, such that valve 9 opens in order to permit liquid to enter from inlet 1 into chambers 10 and 11. Reactivation of the piezoelectric element 6 will then start a new pump cycle.

Fig. 1b illustrates a similar pump concept as Fig. 1a, the main difference being that the outlet side of this micropump comprises an additional valve 15 which separates the outlet 2 from liquid

chamber 7. This valve is controlled by the pressure difference between the outlet 2 and a chamber 14 which is in constant connection (not shown) with the inlet 1 and which is therefore kept in its closed position if the pressure at the inlet side is higher than the pressure at the outlet side and higher than in the pump chamber 11. Thus valve 15 acts as security means against unintended liquid flow from the inlet to the outlet due to higher pressure at the inlet side. This type of valve is intended for use in applications where the liquid reservoir is likely to be submitted to higher pressures than the environment into which the liquid is to be dispensed. Moreover, it can be used to improve the pressure dependence of the pump.

OBJECT OF THE INVENTION

It is easy to understand that valves such as the ones used in the illustrated pumps (for clarity reasons, the cross dimensions of the wafer have been considerably exaggerated with respect to the length dimensions) require extreme accuracy in their manufacturing tolerances which are the more difficult to guarantee, the more valves the pump consists of and the more process steps there are needed for its manufacture.

It is the object of the present invention to provide a micropump which uses a simplified structure without a significant loss of performance or security, and which provides simplification of the manufacturing process as well as cost reductions.

Further the invention has as an object to provide a micropump which is less subject to trapping of air bubbles in areas of slower liquid flow, and which provides therefore improved pump characteristics in this respect.

SUMMARY OF THE INVENTION

These and other objects are obtained with a micropump as mentioned in the introductory paragraph above, and which

comprises further characteristics according to which said liquid inlet is free of any valve, whereby the flow resistance of the liquid inlet is a sufficient amount higher than the flow resistance of the liquid outlet including said valve. Pumps according to this invention are particularly advantageous for use in applications of lower pump rates.

Typically, the pump membrane of a micropump is driven by a piezoelectric member 6 to perform a reciprocating movement. It is of course possible to use any other known type of actuation system such as thermal or magnetic actuation.

Advantageously, the micropump according to the present invention has suction and thrust phases of different duration, whereby the suction phases of the pump cycles are substantially longer than the thrust phases in order to keep the back flow of liquid during the thrust phases as small as possible.

Typically, the pump membrane is constituted from a portion of a wafer, attached in parallel to said plate, and in one embodiment of the invention said liquid inlet and outlet are arranged so as to traverse said wafer, which comprises through-holes at locations corresponding to the valve and the liquid inlet, whereby the wafer is at least partially covered, on its side which is turned away from the plate by connector members, which permit the connection of liquid conduits to the liquid inlet and outlet respectively.

According to a preferred embodiment of the present invention, the liquid inlet and outlet are arranged in said plate, and said wafer is free of through-holes and any rigid cover member on its side turned away from said plate. This arrangement is particularly advantageaous for applications where reduced complexity of the structure is important, as the micropump comprises only a lower glass plate and a wafer which seals the liquid chambers without the need of a covering glass plate and no through-holes in the wafer.

In this preferred embodiment, the resistance of the inlet side is increased by providing a flow channel of restricted cross section or one or more small holes in one of the pump elements which have to be traversed by the incoming liquid flow. The wafer comprises surface structures which are operative as connection areas or spacers between the wafer and the plate and/or as valve members cooperating with a portion of the plate which performs the function of a valve seat.

Advantageously, said plate may be of glass and the wafer of silicon.

The surface structures of the wafer may be produced by a photolitographic-etching process.

According to another advantageous aspect of the preferred embodiment of the present invention, in which the wafer and consequently the valve of the micropump have no through-holes, the valve comprises a pre-tension, soliciting the valve towards its closed position, which pre-tension is obtained by oxidized surface portions of said surface structures of the wafer which perform the function of valve members. This pre-tension defines the working range of the outlet pressure within which the pump will correctly operate. In this embodiment, the valve performs the combined functions of a regulator valve and an outlet valve, which results in the pump having little pressure dependence in the working range.

In a still further embodiment of the present invention, one may provide a cover plate above the back of this regulating outlet valve, in order to form a chamber between said valve and said cover plate, whereby this chamber is in fluid communication with the inlet. Thus, the valve also acts as a security means to prevent unintended liquid flow, due to the application of inlet pressure on the back of the valve.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be described in full detail hereinafter with reference to the drawings, whereof:

Fig. 1a and 1b illustrate two micropumps according to the prior art;

Fig. 2 is an embodiment of the present invention;

Fig. 3 is a sectional view of an embodiment of a micropump according to the present invention corresponding to line III-III of Fig. 4;

Fig. 4 is an elevational view of the micropump of Fig. 3 corresponding to line IV-IV of Fig. 3; and

Fig. 5 is a further embodiment of the present invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 2 shows a micropump according to the present invention, comprising a supporting glass plate 3 and a silicon wafer 4 arranged on top of the glass plate, a portion of this wafer forming a pump membrane 4a. The wafer comprises two openings 1 and 2 which represent the liquid inlet and outlet respectively. The sealing between the glass plate 3 and the wafer 4 may be effectuated by anodic bonding. The upper surface of the membrane 4a is intimately connected to the lower surface of a piezoelectric element 6, such that contraction of the latter in response to the application of a voltage, provided to the piezoelectric element by a control unit 25, results in a downward bulging of the silicon membrane as set out during the description of the prior art. Of course, it is also possible to select the piezo characteristics and the operating

voltages such that the movement of the pump membrane will result in alternative upwards and downward bulging.

The pump comprises two connectors 40 and 41 which cover the wafer 4 at least partially on its side which is turned away from the glass plate 3. The sealing may be effectuated by O-rings. The connectors 40 and 41 communicate with channels 21 and 22 which establish connections between the pump and a liquid reservoir 24 and e.g. a not shown injection needle respectively. This reservoir may be of the volume compensating type or simply a flexible bag-type container such as currently used for various medical applications.

Inlet 1 communicates with flow channel 11' which is active as flow restriction and further with pump chamber 11 which is separated from the outlet by means of valve 8'. Flow channel 11', pump chamber 11 and valve 8' are constituted by surface structures provided in the lower surface of the wafer and are obtained by techniques such as photolitography and etching.

Flow channel 11' may be embodied as a V-groove which can be accurately defined by this type of manufacturing process.

The connector 41 also serves as a cover member for liquid chamber 42 which is an expansion space for chamber 43 during the thrust phases, where the portion 44 of the wafer, which forms valve 8', bulges upwards.

The following is a description of the operation of the micropump according to Fig. 2.

Activation of the piezoelectric element 6 produces a downward bulging of the membrane 4a, thus increasing the pressure in pump chamber 11. As a consequence thereof, valve 8' opens because the flexible part of the valve 8' bulges upwards, due to the increased pressure in the liquid. Liquid may now flow from the pump chamber 11 through the open valve 8' into the outlet 2 and further to the injection needle.

Upon deactivation of the piezoelectric element 6, the membrane 4a returns to its straight position, so that valve 8' closes due to the pressure release and simultaneously, liquid is drawn in through inlet 1.

During the above described thrust phase of the micropump, in which the volume of the pump chamber 11 is decreased, a certain amount of liquid will also be pressed backwards into the inlet, since the latter is not closed by a valve. The author of the present invention has found, that satisfactory pump performance may be obtained even without such valve at the inlet side, if the flow resistance at the inlet side of the pump is sufficiently higher than the flow resistance at the outlet side.

If this condition is met, the amount of liquid which flows backwards during the thrust phases of the pump is small compared to the amount of liquid flowing forwards during the suction phases and the pump may therefore be fully operative without a check valve at the inlet side such as used in the prior art (valve 9 of Figs. 1a and 1b). During the suction or aspiration phase of the pump cycle, valve 8' is closed and the full pressure difference between inlet 1 and the pump chamber 11 acts to draw liquid into the pump chamber. To the contrary, during the thrust phases valve 8' opens and the pressure difference between outlet 2 and pump chamber 11 is considerably smaller and decreases rapidly. This means that the pressure in the pump chamber does not strongly rise during the thrust phases, since the liquid may more or less freely escape through the open valve 8'.

Consequently, the pressure difference between the inlet and the pump chamber during the suction phases is much higher than the reversed pressure difference during the thrust phases, and as a result thereof, the amount of liquid flowing through the inlet in backward direction during the thrust phases of the pump is much smaller than the amount of liquid flowing through the same inlet in forward direction during the suction phases.

The flow restricting channel which is connected to the inlet is a schematic representation of a means for providing relatively high flow resistance in the inlet and may be embodied by various other known constructions.

Further to provide a small loss at the inlet side of the pump, it is also possible to increase the duration of the suction phases of the pump cycles with respect to the duration of the thrust cycles. Thus, due to the non-linear pressure/flow characteristic, the ratio between the amount of backward flowing liquid to the amount of forward flowing liquid may further be decreased. In addition, such provision is advantageous for increasing the pump rate as there is no need for continuing the thrust cycle after the outlet valve has closed itself. The outlet valve closes due to the pressure release as soon as sufficient liquid has flown from the pump chamber through the outlet.

Fig. 3 is a sectional view along the line III-III of Fig. 4, wherein corresponding parts are designated by the same reference numbers as in Fig. 4. It is apparent that the liquid inlet communicates with flow channel 11' which opens into the pump chamber 11. Due to the simple geometry of the flow channel 11', the liquid inlet side comprises no portions in which air bubbles may be trapped and the operation of the pump is therefore considerably more reliable. Advantageously, the membrane sizes are defined by shallow etching in order to obtain satisfactory shape control.

Fig. 4, as mentioned above, shows another, preferred embodiment of a micropump according to the present invention. Here, the glass plate 3 comprises two cross borings which act as liquid inlet and outlet respectively. The liquid inlet 1 is provided at its lower end with a polymeric connection member 23 which establishes connection of the pump with reservoir 24 through conduit 22, whereas the outlet 2 is provided with a polymeric connector 20 which establishes connection of the pump to the injection needle via conduit 21. One difference between the embodiments of Figs. 2 and 4 is the arrangement of the inlet and

outlet borings which, in the case of Fig. 4 traverse the lower glass plate 3, whereas in Fig. 2 they traverse the wafer.

Valve 8' is comprised of a valve membrane 8a which carries an annular projection 8" on its lower surface, which projection is concentrically arranged around the outlet boring 2 in a manner as to abut on an annular surface area 27 of the glass plate 3 surrounding the outlet boring 2. Either the projection 8" or the membrane 8a or both carry an oxide layer 8b in order to maintain the valve in its closed position due to a certain desired pre-tension provided by this oxide layer.

The lower surface of the wafer further comprises connection areas 4', 4" at which the wafer is connected to the glass plate in water proof manner, whereby the sealing may be effectuated by anodic bonding.

The main difference between the two embodiments of Figs. 2 and 4 respectively lies in the operation of their valves. Although valve 8' of Fig. 4 is no check valve and, contrary to the valve of Fig. 2, valve 8' of Fig. 4 tends to be opened by the outlet pressure, it remains closed as long as the outlet pressure is not too high because the pre-tension provided by the oxide layer on the valve acts in this direction. On the other hand, pressure in the outlet helps to open the valve more easily during the thrust phases, so that this valve partially combines the functions of the two outlet valves of the prior art as long as the pump is operated in the designed pressure range. It functions as a regulating outlet valve for a chosen influence of the outlet pressure on the pump rate. Usually one would desire a very small pressure dependency. To achieve this, the surface on which the outlet pressure works should be a small portion only of the total valve surface as indicated in Figs. 3 and 4.

A further advantage of the embodiment of Fig. 4 over the one of Fig. 2 is that the wafer of Fig. 4 does not need any through-holes and simplifies thus its manufacture.

Fig. 5 illustrates a pump embodiment having an outlet regulator valve 8' which is arranged such as to form a permanent separation between the outlet and a compensation chamber 14' which is in connection with the inlet 1 in order to apply the inlet pressure on the back of the outlet regulator valve as schematically indicated by the dashed connection line 14". The outlet regulator valve 8' combines the functions of the outlet valve 8' of Fig. 4 and of the security valve 15 of Fig. 1b.

On the inlet side, the pump according to Fig. 5 comprises a restricted flow channel 11' which communicates with the inlet 1 and with pump chamber 11. All other elements of the pump of Fig. 5 are similar to the respective elements of the pump of Fig. 4 and similar elements are therefore designated with the same reference numbers.

The invention has been described with reference to embodiments by way of examples only without being limited thereto, and covers also modifications which appear obvious to the expert in the art.

CLAIMS

1. Micropump comprising at least one liquid inlet (1), a liquid outlet (2), a pump chamber (11) between said liquid inlet (1) and said liquid outlet (2), said pump chamber (11) being formed between a plate (3), and a pump membrane (4a) which is capable of reciprocatingly increasing and decreasing pressure in said pump chamber (11), wherein said liquid inlet (1) is separated from said liquid outlet (2) by a valve means (8, 9, 15), comprising at least one valve (8') between said liquid outlet (2) and said pump chamber (11) and operating such as to permit flow of liquid from said pump chamber (11) to said liquid outlet (2) when the pressure in the pump chamber (11) is increased, characterized in that the liquid inlet (1) is free of any valve, whereby the flow resistance of the liquid inlet (1) is a sufficient amount higher than the flow resistance of the liquid outlet (2) including said valve (8').

2. The micropump of claim 1, characterized in that said membrane (4a) is driven by a piezoelectric member (6) to perform a reciprocating movement.

3. The micropump of claim 1 or 2, characterized in that the suction phases of the pump cycles are substantially longer than the thrust phases.

4. The micropump of any one of claims 1-3, characterized in that said membrane (4a) is constituted from a portion of a wafer (4) attached in parallel to said plate (3), said liquid inlet (1) and outlet (2) being arranged in said wafer (4) , and in that said wafer is at least partially covered on its side turned away from said plate (3) by connector means (40, 41), permitting connection of liquid conduits to the liquid inlet (1) and outlet (2) respectively.